54 Process Automation in the Automotive Industry

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INTRODUCTION

The automotive industry is a good example of an industry that has seen significant changes as a result of introducing automation in the manufacturing process. It is well known that the first car automotive plants were labor intensive and created a large number of jobs in the communities in which they were located. The introduction of automation into this industry proved controversial. Whilst leading to substantial cost savings in the manufacturing process, there was also a social cost with many people who had previously undertaken these manual, labor-intensive processes finding that their jobs had been replaced by machines. Despite the controversial nature of the development, it is clear that the introduction of automation has brought substantial benefits to both consumers and manufacturers—the most obvious being the reliability in product provided by the ability to manufacture to a repeatable, quality controlled process.

Significant benefits have been achieved through the introduction of both robotics and automation into plants. The term “robotics” refers to the science and technology of robots. In contrast, the term “automation” has a broader scope covering both the operation of the robots themselves as well as other aspects of a manufacturing process. There is a perception within the general public that “automation” and “robotics” are terms, which are synonymous. Indeed, media reports on the automotive industry typically feature images or videos showing robotic assembly lines. However, in practice, the terms can refer to very different contexts. The automation of a robot is the job of the robot developer. In contrast, the automation of a plant is the job of a manufacturing or control engineer with a very different remit and focus. This chapter describes automation techniques as applied to the development of a factory rather than of a specific machine within it. As will be explained in the following sections, some parts of the manufacturing process make use of robotics, however typically all will make use of some process automation (PA) techniques.

PLCs, PACs, AND SCADA IN THE AUTOMOTIVE INDUSTRY

The prime device of choice for achieving PA in the automotive industry is what was historically known as the programmable logic controller (PLC). It is well recognized that the automation industry has strong ties with the automotive industry with the development of the PLC taking place in response to the desire of General Motors to replace their inflexible relay logic automation systems with microprocessor based control in the 1960s. Nearly 50 years on, the PLC continues to be used extensively in manufacturing operations, albeit under a new name: “Programmable Automation Controller” (PAC). Automation vendors have selected this new name in order to differentiate these modern, sophisticated devices [1]—which support an extensive feature set—from the early PLCs. Despite the change in name, the concept ultimately remains similar: the controller is a platform with guaranteed long-term support, on which a process control algorithm can be implemented.

The promise of vendors to support automation controllers for periods of 15–20 years is one of the reasons why dedicated automation hardware continues to play a part in manufacturing industry. Other reasons include design for the industrial environment (e.g., controllers typically do not have a fan: a mechanical component, which is liable to fail if used continuously over an extended period of time) and the security provided through the use of a device about which the general public have limited knowledge. The alternative approach of using commercial PCs has its advocates owing to the faster speed of the processors. However, the use of PCs for industrial control remains limited in scope owing to concerns about long-term support for both hardware and software. Security concerns associated with the vulnerability of controllers using Microsoft Windows-based operating systems mean that this approach is generally not in favor.

One major difference between the early PLCs and PACs is a feature set that meets the needs of manufacturers in the twenty-first century. This covers various aspects. For example, whilst PLCs provided the ability to program the controllers exclusively with ladder logic, the historical language for programming the devices, newer controllers provide support for the range of languages defined by the IEC61131-3 standard in 1992. In addition to ladder logic, four further languages are defined [2]. These languages are

- Sequential function chart (SFC)
- Instruction list (IL)
- Function block (FB)
- Structured text (ST)

This suite of languages provides the ability to select a tool to fit the needs of individual applications. As will be described in Standards and Code Generation section, however, there are various reasons why an automotive user might select one language over another.

In addition to the changes in programming techniques, PACs have the added advantage of enhanced communication capabilities that are much better than their predecessors. This presents several advantages. As well as improving the speed with which diagnostic information and faults can be got to factory maintenance teams, the current generation of PACs is designed to allow simple configuration of the communication between the constituent components of an automation system. On one level, this covers factors such as the communication between sensors and controllers, and interlocking between controllers. On another level, this covers the interface between the human–machine interface (HMI) or supervisory control and data acquisition (SCADA) system and controllers. On a third level, the newer controllers also facilitate the connectivity to enterprise management software (EMS).

A key benefit of the integration between EMS and the production environment is the potential to bring production scheduling data into the manufacturing facility. This communication is needed where a manufacturer has implemented some form of build-to-order. Close integration between the information system of an organization and its production system allows a faster response to orders not to mention the ability to eliminate manual transfer of data from one domain to the other. An example is the entry of an order by a dealer into the manufacturer's order management system. Typically, a dealer can immediately give their customer indication as to when their car will be built. The order in turn will be allocated to a factory and built according to the customer's specification—without further human intervention.

A further consequence of the integration between the production environment and sophisticated production management tools is an enhancement in the quality of the diagnostic information available within the production environment. Although traditional PLCs were designed to allow fault-finding, PACs, together with appropriate software, facilitate the measurement of plant metrics over a long period of time. These data allow for consistent faults to be analyzed by maintenance teams, and also give production managers the ability to understand the efficiency of their facilities.

CONSTITUENT PARTS OF AN AUTOMOTIVE PLANT

When looking at PA systems in the automotive industry, it is simplistic to consider all of the automation systems within a factory as a single entity. The automotive manufacturing process consists of a number of constituent parts, each with their own needs, principles, and priorities. The main steps for manufacturing a vehicle are shown in Figure 54.1.

Press Work

The press work is the section of a factory in which panels made of the metal of choice (typically steel or aluminum) are formed into the components used to make up the car body. Press works make use of dedicated machines for each part of the process, with a part having to pass through one or more presses before it is ready to be used in assembly. There are two aspects to the automation of a press. A modern press will have its own control system, which is an integral part of the machine. This is a development from traditional hydraulic presses, which made use of manual control of valves for the control of the press operation. Newer presses have provided

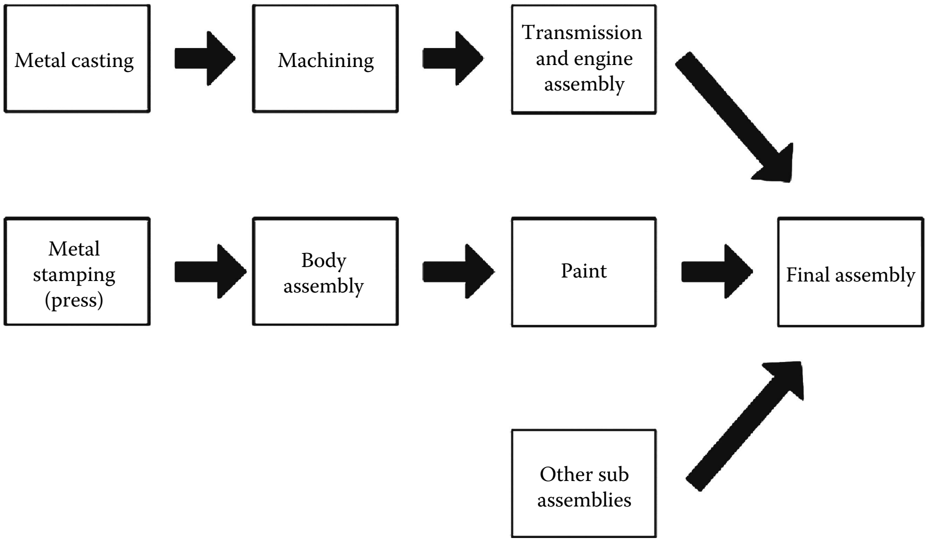

FIG. 54.1
Steps for manufacturing a vehicle.

productivity and quality improvements through the use of programmable control, giving increased speed and enhanced performance monitoring capabilities.

In some cases, the use of automation for the machine control system (MCS) has led to the introduction of automated feed mechanisms. An example of this is the use of a robot for loading panels and unloading completed parts from a press. Some manufacturing processes also require the transfer of a part from one press to another. Now, rather than being an independent MCS, the automation becomes a line control system with the function of coordinating the control systems of multiple machines with the transfer mechanisms supporting them. Introduction of automation has therefore allowed for the throughput of the machines to be increased.

Given that a press is a comparatively simple machine, its control system is also comparatively simple. As is the case with any MCS, the most important component is the controller. Coupled to this will be an HMI panel for the configuration and monitoring of the device. The second aspect is the mechanism by which input/output (I/O) signals are received by the controller.

One mechanism by which connectivity to I/O is achieved is to wire sensors and actuators to connection points on a card local to the controller itself. The alternative approach is to use distributed I/O with an industrial network providing the communication between the two parts of the control system. The choice of whether to use distributed or local I/O is made by the manufacturer of the machine and will be determined by the physical layout of the devices on the machine as well as the respective purchase prices of the two approaches. In contrast, where a press forms part of a line, I/O connectivity is most likely to be achieved using distributed I/O to reduce the cost of wiring sensors and actuators to the controller. Although the speed of the mechanical components will be the primary limiting factor, a high-speed control system is desirable so as to allow a high number of parts to be processed in a short period of time.

The mechanical constraints within which a press has to operate mean that there is often limited scope for a press to facilitate the rapid changes needed by a manufacturer working with flexible manufacturing processes. This is owing to the time taken to change the tooling from one process to another. In contrast, the reconfiguration of the control system will be a fast process.

Engine and Transmission

Different manufacturers have differing approaches to whether engines and transmission systems are built together. However, in the case of both types of engines and transmission, there is a common theme in that the manufacturing process consists of two operations: high-precision machining to create the components followed by an assembly operation in which the machined parts are put together to form a complete engine or transmission system. For example, an engine plant may have two separate parts, the first in which engine blocks, pistons and cylinder heads are machined, and the second in which the components are assembled to form a complete engine.

Like a press work, manufacture of engine components is undertaken using specialized machine tools with their own integrated automation systems. These specialized tools allow components to be prepared with a high level of precision. Transfer systems are used to allow parts to pass from one station to another. The nature of the processes means that in a modern plant, few human operators are visible in this part of the factory.

In contrast to machining, an engine assembly line is more labor intensive as the processes that require more dexterity than is possible with robotic manipulators. Within engine assembly, there are again two phases—the first in which the engine block, cylinder head, pistons, and other internal components are assembled, and a second in which external parts such as fuel injectors, belts, and the exhaust manifold are fitted. The first phase is typically a continuous process in which engines pass along an assembly line with operations taking place in sequence. The second phase may not necessarily require operations to be completed in sequence. For example, some of the newest factories make use of automatic guided vehicles (AGVs) to transfer part-built engines from one location to another. These AGVs are loaded with the correct parts, and the AGV moves an engine to the station at which the required task or operation is completed.

These assembly techniques present challenges for the automation system. Given that a line in a plant may be used for the construction of multiple engine variants, there is a need to maintain careful control of the engine type that is under construction. A technique for achieving this is to fit a radio frequency identification (RFID) tag to the cradle holding the engine. This tag is loaded with the required variant type at the start of production. As the engine cradle moves through the plant, either on a line or on an AGV, the tag can be read using handheld scanners (by human operators) or automatically by the automation system to enable the variant to be identified. Parts appropriate for that variant can then be identified and fitted to the engine under construction.

Furthermore, the use of AGVs places additional demands on the automation system, which needs to provide a communication mechanism between each AGV and the static part of the automation system. As well as taking responsibility for the correct operation and routing of a vehicle, the automation system also has to ensure that the vehicle operation does not endanger humans working in the vicinity. The safety system associated with an AGV has different aspects. On one level, the safety system of an AGV has to operate independently. This means that an emergency stop local to the vehicle itself will make it stop. On a system level, it may be necessary to command an emergency stop remotely—for example, if a potentially dangerous situation is seen by an observer. In this case, there needs to be a mechanism by which the stop signal can pass to the AGV, which in turn can respond to it. One mechanism by which this is achieved is through the use of programmable safety systems together with wireless communication technology.

Body Assembly

When one considers an automated manufacturing line, it is typically a body spot-welding line that comes to mind. However, alternative fixing processes such as riveting and metal inert gas welding may be used by some manufacturers. Regardless of the process, in most factories in the high-cost economies, car body assembly is a heavily automated process. The manufacturing process is undertaken in cells, many of which make use of robots for assembling the car panels together. Different components are assembled separately, and then brought together to form a complete car body.

The PAC plays a major part in the control of a car body assembly line. Although actual implementation of many processes is done by robots—which are programmed separately with their own specific processes—an important part of the body assembly process is the coordination and control of the component transfer systems, the initiation of a robot control sequence and the interface to the device responsible for the assembly operation (e.g., weld controllers). The process in a typical cell may consist of the control of operations to move the components into location, confirmation of presence, operation of fixtures to hold components into place followed by actuation of a robot. Once a robot sequence has commenced, further signaling may take place between the programmable controller and the robot to allow a device on the robot end-effector to be controlled. An example of this is a weld controller that needs to be triggered when a robot is at the correct location. Good communication between the weld controller and the robot to ensure that the welds are made as planned.

The number and type of devices used in the cell will be defined by a manufacturing engineer as part of the planning of the assembly process. A key aim of the planning process is to keep the cycle time, or the time taken to complete the operation to a minimum. Fast cycle times are desirable as they reduce the amount of time taken to construct a vehicle. The desired cycle time for a particular cell will, for example, determine the number of robots needed for a particular operation. A large number of robots, each dedicated to one operation will give a fast cycle time but is expensive. In contrast, a single robot to which multiple tools can be connected is cheaper to purchase. However, the design tradeoff is that it will require more time in which to complete the operation as the operating cycle has to include time for detachment and reconnection of the robot. The supporting automation system will have the flexibility to facilitate both strategies.

Given the nature of a body assembly cell with a large number of often diverse devices, there is a need for communication between sensors, actuators, and the controller. When the early PLCs were in use, this connectivity was achieved using complex wiring looms that brought a pair of signal cables from each device back to the controller. Although older installations continue to follow this approach, more recent installations make use of distributed I/O together with an industrial communication network for achieving communication between the devices and the PAC. An HMI is needed for control and monitoring purposes, and this is typically connected to a second network. A wide range of options for achieving this networked communication are available. The choice of communication mechanism is based on a number of factors including throughput, communication mechanism, and physical connectivity. Application specific requirements—such as the ability to establish communication with the nodes on a detachable tool changer within a short period of time will also play a part in determining the network of choice.

A body assembly cell will typically be constructed to operate with a number of operation modes including manual, auto, and step. Manual mode allows all functions within the cell to be operated manually by an operator. This is needed during the construction of the facility to ensure that the assembly operation is configured correctly, and also during normal operation to provide a mechanism by which to recover the operation of the cell in the event of a fault. Typically, this mode will only allow low-speed operation of robots. In contrast, the automatic operation mode will allow all equipment to operate at full speed, and is the normal mode of operation when the facility is in production. The step mode is designed for troubleshooting in normal operation. In the event of a fault occurring during normal production, it allows a mechanism by which the fault can be corrected by an operator, who then operates the program through to the next step before recommencing the normal mode of operation. These modes of operation are all implemented programmatically within the PAC.

In parallel with the design of the primary function of an assembly cell, a safety risk assessment will need to be conducted to ensure that operators are not at risk when the machinery is in operation. As is the case for all machinery, this evaluation has to assess potential risks, the likelihood of occurrence and the severity of injury. Based on this assessment—as well as legal requirements specific to the country in which the plant is located, a machine safety system will be developed to mitigate these risks. Various strategies are possible for achieving machine safety. Many installations make use of traditional hard-wired installations in which the emergency stop buttons and door interlocks are connected to a series of safety relays—which in turn are connected to the safety contacts of the machinery. More recent installations may make use of a dedicated safety controller and a networked safety system in order to ensure that the manufacturing cell operates in a way that minimizes the risk of injury to operators. The newest installations are starting to implement systems with a single controller that both implements the required control algorithm, and at the same time provides the necessary monitoring of the safety system.

Paint Shop

After assembly, completed car bodies pass through a paint shop in which they are treated to avoid corrosion, and painted—a procedure that provides further corrosion protection as well as providing cosmetic benefits. The design of painting systems, therefore, has to meet both of these needs, as well as ensuring that the process meets the environmental regulations that prevent the raw materials used in the process from being dispersed.

There are certain aspects of a paint shop automation system, which are common to body and final assembly lines—notably the transfer system for transporting the car bodies through the paint shop. Although the profile of the moves may be different (e.g., electro-dip painting requires bodies to be lowered into a pool)—the way in which a transfer system is realized is the same: signals from a programmable controller to drives, which in turn control the motors that transfer the part-built cars. There is one aspect of automation in a paint shop, which is very different from the other sections described here. Like the distributed control systems (DCSs) used in the process industries, paint shops make use of analogue loops to control the flow of material, as well as the temperature of the ovens used to bake the paint. This is in contrast to most of the other operations used in automotive manufacture, which are reliant on digital logic.

Final Assembly

After a car body has been painted, it passes through the final assembly line. Although automation has changed the way in which processes have been implemented in the other parts of the car assembly process, the nature of the processes—many taking place inside a moving, part-built car—continue to rely extensively on manual operations. However, automation does play an important role within the part of the factory. Unlike body assembly lines where manufacture is often static, most processes in the final assembly line are continuous in that they are conducted while the vehicle is moving. The programmable controllers are therefore responsible for maintaining control of the conveyers and transport systems that move the part-built cars through the assembly line. In contrast to body assembly cells, the emphasis of the control system is on the management of start and stop signals and setting and maintaining a speed rather than the constant signal exchange between devices. Specific manufacturing cells, however, may continue to have characteristics more similar to those in the body assembly line.

An example of a final assembly facility that has characteristics similar to a process in body assembly is a glazing cell, in which sequenced panes of glass are fed to a robot, where they are picked up and placed into the correct parts of the car body. Similarly, stuff-up cells, in which suspension and transmission subassemblies are fitted to the car, are also heavily automated. In both of these examples, the manufacturing cells will bear a resemblance to those in the body assembly section and the automation control system will undertake a similar process of signaling between robots, transfer equipment and PAC.

Recent trends within car plants have meant that the number of variants build within a single manufacturing line has increased. This has permitted the use of manufacturing equipment for multiple products, where in the past a line might have been dedicated to a sole model. As well as presenting challenges from the perspective of the assembly fixtures, flexible manufacturing techniques have presented challenges to manufacturers in terms of ensuring that the correct parts are fitted to each model. The automation system therefore plays a major part in the error-proofing systems used within these flexible plants. RFID tags are used to identify the variant, and then dispense the correct part.

Similarly, use of advanced tooling has opened up the possibility of collecting and storing production information both for quality and liability reasons. In response to legal frameworks in the countries in which their products are used, some manufacturers have opted to implement mechanism to store information on safety critical functions so as to confirm that when a vehicle left the manufacturing plant, it was fit for purpose. An example of this is power tooling that is able to report the torque and angle of a joint to the production management system.

STANDARDS AND CODE GENERATION

It is a commonly held view that code to operate automation systems in automotive plants is based exclusively on ladder logic, the historical programming language for PLCs. There is a further perception that the language, though well suited for simple systems requiring troubleshooting at the bit level, is inflexible and difficult to use in large systems. An insight into why this is the case was provided by Lucas and Tilbury [3], who conducted an observational study into the software design process in a body assembly plant. They found that the logic design process is heavily reliant on experienced programmers who adapt existing code to suit the application in question. As a consequence of this, it becomes challenging to promote consistency within a plant or line—a factor relevant to both controller and HMI systems. In response, most automotive manufacturers have developed in-house standards that specify all aspects of a control system [4].

A standard covers all aspects of control system design, from specification of hardware through to the design of operator panels. These standards also specify how software and HMI screens should be structured together with the definition of the interfaces between different components. Often, a standard also defines how the code should be structured. The advantage of a standard is that it promotes consistency within and between factories—a factor that becomes increasingly important as the automotive industry moves toward the support of multiple facilities globally using a single engineering team. The disadvantage of a standard is that it limits the flexibility of the programmer. Furthermore, the implementation of a standard brings in the need for compliance checks to ensure that integrators building the system have developed systems according to the specification.

Survey work has shown that there are a number of common themes between the standards adopted by automotive manufacturers, though the mechanism by which these goals are realized is quite different. Taking the example of software, there are a number of factors that determine the structure of code adopted in a particular plant. These include the choice of vendor and the mechanism by which a particular plant is supported. The key themes identified in Hajarnavis and Young [4] were relay ladder logic, with each operation being conditional on a set of conditions, step-based ladder logic, in which a variable step number is used to identify and control a particular operation, SFC, together with FBs and finally dedicated design automation tools.

Research has also shown that broadly speaking, typically, users of Rockwell Automation processors opt for ladder logic, with the United States favoring the relay ladder logic approach, with European users preferring the step number-based approach, whereas users of Siemens processors prefer to use multiple languages with the final operation structured with an SFC. In all geographical regions, there is a tendency to select a local automation supplier on account of the support available from the vendor. This implies that the selection of programming language used in an automotive plant is a function of the level of support available locally to that manufacturer.

A number of initiatives have been presented in response to the challenge of maintaining consistency and promoting reusability of control code. It is recognized that some form of formalized tool is needed to bring structure to the code development process. Two options proposed by academia include the use of the unified modeling language [5] and as well as the use of Petri-nets, a mathematical tool for the modeling and synthesis of systems as an alternative standard. Despite evidence to suggest that this tool may present some benefits to an automotive end user [6,7], there has been little enthusiasm for adopting these approaches. Reasons proposed for the reluctance to implement this technique in practice include the mechanisms by which the models developed using these tools are mapped to control code, the skill level of the programmers undertaking the work as well as a reluctance to change.

A further reference in this area is the IEC61499 standard that defines how FBs should be defined [8]. Like the IEC61131 standard, it has the potential to influence the standards used in the automotive industry. Although it is claimed that the first industrial solutions, which make use of the standard are starting to indicate broad acceptance [9], a counter viewpoint is the claim that the standard fails to go far enough in terms of bringing current software engineering practices into the development of industrial process systems [10]. Though arguably, the greatest barrier preventing the use of this standard in the car industry is the fact that industrial-grade implementation platforms are not widely available [11].

In parallel with developments in academia, some automation vendors have opted to implement tools for generating code from a master library, thus eliminating the scope for variation from the specification. However, this in turn presents challenges from the perspective of monitoring and recording changes, which might be required during the installation of the system. In addition, there is a lack of agreement as to the structure of the generated code—which may not be optimized for the processor in which it is used. Code generation, by its very nature provides a result that has greater complexity. This in turn undermines the ability to obtain diagnostic information at the code level. For this reason, the use of industrial code generation tools is not widespread, though there are some factories that use one these commercial tools as their standards.

DIGITAL MANUFACTURING IN THE AUTOMOTIVE INDUSTRY

A key theme that is starting to have an impact on the design of automation systems in automotive plants is the concept of digital manufacturing. This is a concept that allows production facilities to be designed, tested, and deployed faster through the use of sophisticated software tools. The first generations of these tools focused on the ability to create a virtual prototype of a facility. Subsequent enhancements allowed for simulation of the models to allow for testing prior to implementation, allowing for potential problems to be identified prior to actual construction of the plant.

Relating this to an automotive plant, this means that the tools used to design the production facility (an example being DELMIA from Dassault Systems) to be integrated so that the mechanical, electrical, and controls components can be synchronized. The implication of this is that it opens up the possibility to defining the functions used within a plant within the engineering design environment, and mapping this to code used within the programming environment. These techniques extend the concept of the previous standards through the definition of components in both the design and programming environments. The main tenet of approach is the definition of smart devices in the design environment, which are mapped to FBs within the software development environment.

An example of the approach is shown in Figure 54.2, which shows how models developed in the DELMIA environment are mapped to code in a Rockwell Automation PAC. This shows how a library device created by a mechanical engineer in DELMIA can be exported, and imported as an add-on instruction. The code for the FB can then be created. Once libraries of devices have been combined in DELMIA to form the definition of a manufacturing cell, it can be exported for use in the RSLogix 5000 programming environment. This definition creates the tag structures needed by the controllers in order to communicate with physical devices. Should further modification be made using the programming tool, a program can be exported, and reimported within the DELMIA design environment. This shows that the process is bidirectional, with changes possible in both environments, with the

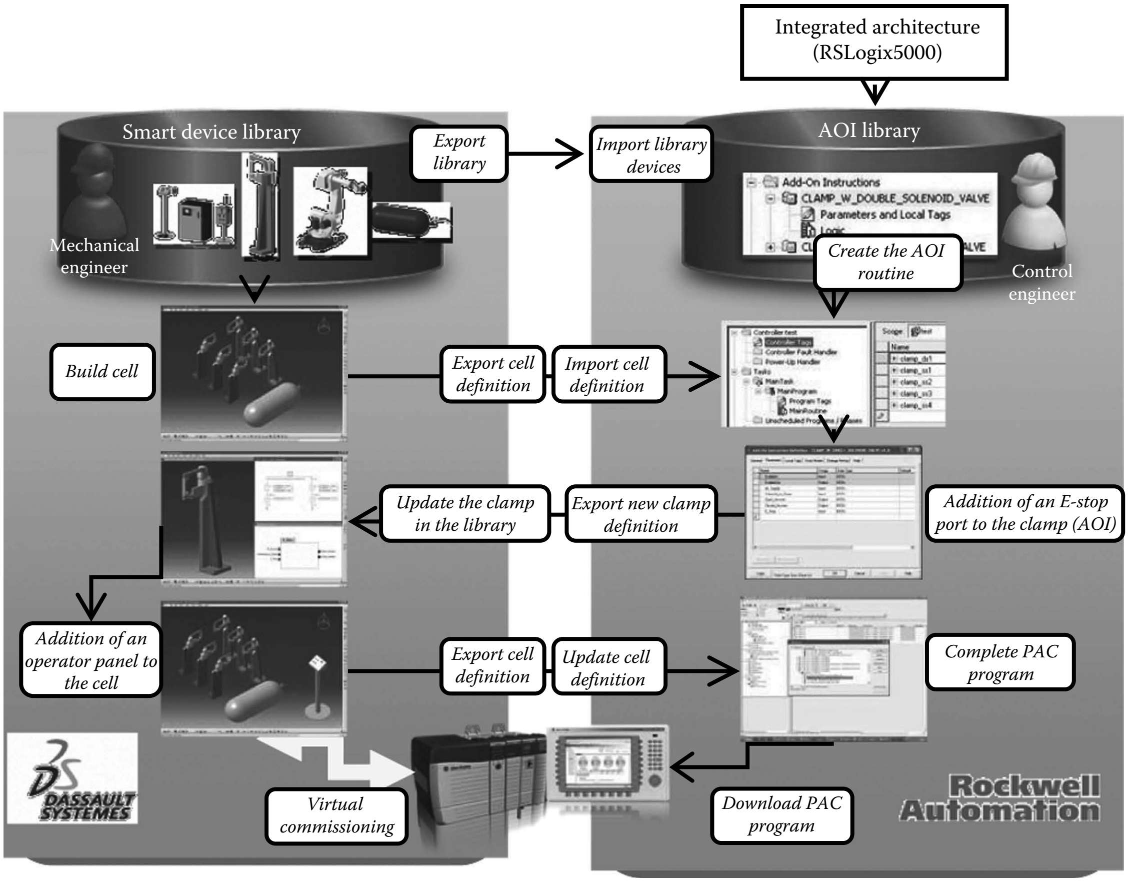

FIG. 54.2

Example of integration between PAC and design software. (From Didier, P. et al., Converged Plantwide Ethernet, Design and Implementation Guide, Rockwell Automation and Cisco Systems, 2010.)

export–import procedure used to ensure that both the model and the actual code remain synchronized with each other.

The challenge with the concept is the development of common interfaces between all of the relevant components. This has stimulated standardization activity between automation vendors to establish a common interface between their devices. An example of an organization, which has conducted work in this area is AutomationML, a consortium of automation vendors [12]. AutomationML defines information about topology, geometry, kinematics, logic, and the relations between them. Like the other tools for bringing structure into the development of control systems, AutomationML makes use of object-orientation. At present, it is difficult to predict if the work of this consortium will gain widespread acceptance by global car manufacturers.

FUTURE TRENDS IN PLANT AUTOMATION

Agility

Agility in manufacturing automation can refer to multiple concepts. On one hand, agility can refer to the speed with which a new model can be introduced into a manufacturing plant. On the other hand, it can refer to the means by which the product mix in a flexible plant can be changed in response to the change in demand. From the perspective of a car manufacturer, it can also refer to the ability to offer their customers a wide range of customization options whilst maintaining the cost base of mass manufacture.

These factors have an impact on how factories are used. In historical factories, a production line might be dedicated to the construction of one type of vehicle. In contrast, a contemporary plant will build several different vehicle types using one line. This allows assets to be used more effectively than is the case if a manufacturing line is dedicated to one type of vehicle. However, the offer to customers of a range of customization options has an impact on the machinery used to build the vehicles. Increased flexibility is therefore needed to facilitate the construction of vehicles with these variations. Clearly, there is a desire to do so whilst maintaining the low cost base of high-volume automated production. This places demands on the automation system that has to have the ability to respond to the desire to construct multiple products using the same equipment. One of the challenges faced in a flexible plant is to maintain quality control, specifically to ensure that the components designed to be fitted to one vehicle are not used in another. An example of how this can be achieved is given by General Motors that integrated a number of error-proofing stations into the automation system of their Ellesmere Port factory [13].

Although not all manufactures intend to implement a form of "build to order," experimental work has shown that some programming tools are better suited to the implementation of process changes faster and more effectively than is the case for other programming tools [14]. Clearly, this shows that a manufacturer wishing to implement an agile manufacturing paradigm should ensure that the characteristics of their control system are well suited to their approach to production. A manufacturer planning for the future would therefore be advised to ensure that adequate analysis of tools has been conducted before selection.

Safety

As is the case with any manufacturing facility, manufacturers are legally obliged to take steps to ensure that machine operators are not at risk while they are working in the production environment. Although the specific details will be determined by the legislation local to the country in which the manufacturer operates, typically, this involves a process of conducting a risk evaluation to determine the chances of an operator getting injured, the potential severity of injury, and the likelihood of occurrence. The EN954 standard provides guidance on how this process can be achieved. Once risks have been identified, steps need to be taken to ensure that the most severe risks are minimized. This will normally consist of the design of a safety system to ensure that hazardous operations cannot take place unless it is confirmed that there are no operators present.

At the same time, a safety system needs be designed to ensure that the operations needed for the normal operation of the factory or manufacturing cell can be achieved. Taking the example of a robotic body assembly cell, restricting the operation of the robot to times when there is no operator present prevents the ability to program and configure the robot. It also reduces the scope for recovery if the programmed sequence does not proceed as planned. At the same time, operators should be excluded from the assembly cell when the robot is running at full speed. One mechanism by which this can be facilitated by the safety system is through the definition of two modes of operation. A manual mode can be defined for configuration, programming, and error recovery in the cell. This mode restricts operation of the robots to a low speed of operation and is enabled by default. Closure of door interlocks can in turn enable the second mode, allowing full-speed operation of robots located in the cell while ensuring that there are no operators present within the area where there is a risk of injury.

Historical safety systems made use of dedicated relays to interface emergency stop buttons to other safety hardware. This required the routing of power supplies and control signals through a number of safety relays. Often, these hard-wired systems make use of dual channel signaling, which allowed for the comparison between the signals on each channel. However, the inflexibility of using a hard-wired safety system has presented challenges to some automobile manufacturers owing to the need to rewire the safety system in response to changes in production requirements.

A solution is the use of programmable safety controllers that bring the benefits of programmable control and networked control systems into the safety domain. Programmable safety systems differ from traditional control systems in that they make provision for how the system should behave in the event of a fault. In the case of industrial automation, this typically means "fail-safe" operation such that a problem will lead to the protected machinery being set to a state in which the risk of injury to operators is minimized. One way in which this is achieved is through the use of multiple processors. As well as their primary function of monitoring safety signals, a consistency check is conducted between the processors to ensure that the result of their processing is consistent. The operating system of the processors is designed such that an inconsistent result will lead to an emergency stop situation. This approach is in contrast to the safety systems in aircraft control systems where a voting system is used between multiple processors to ensure that the aircraft always remains in operation. The implication of a "fail safe" system is that a fault may lead to a loss of productivity, but it will not endanger the operators of the machine.

A further advantage of using programmable control for safety systems is the ability to configure I/O devices such that they send test pulses to monitor the integrity of the wiring. Should these test pulses become absent, the safety system can respond accordingly by triggering an emergency stop situation. In the minds of some practitioners, this provides a better solution than is the case of traditional hard-wired safety systems—where a wiring change might go undetected, putting the effectiveness of the complete system at risk.

Coupled with the use of programmable safety controllers is the use of safety networks. These use a variety of communication mechanisms. For example, SafetyBusP and DeviceNet are both based on the Controller Area Network (CAN). In each case, the application layer protocol ensures appropriate behavior of the network in the event of failure. To give an example, the CIP safety application layer protocol used by DeviceNet and EtherNet/IP differs from its standard counterpart by defining shorter timeouts [15]. An example of how the safety system of robots might be integrated is shown in Figure 54.3.

The technical capabilities of the safety network solutions differ in terms of how they are used. For example, SafetyBusP is a dedicated network for safety devices. In contrast, DeviceNet and EtherNet/IP allow both standard and safety devices to share the same media. The choice of approach follows from the communication strategy of the end user. Like traditional industrial communication networks, safety networks are going through a process of evolution. For

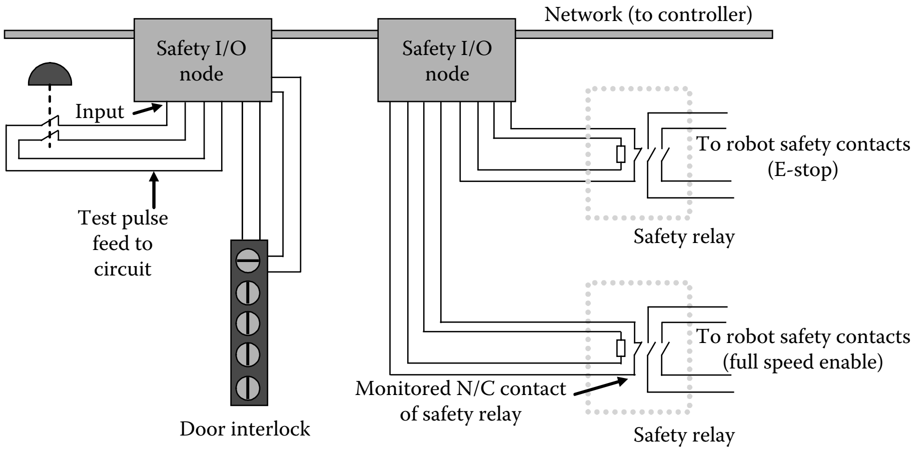
Network (to controller)
Safety I/O node
Safety I/O node
Input
Test pulse feed to circuit
Door interlock
To robot safety contacts (E-stop)
Safety relay
To robot safety contacts (full speed enable)
Monitored N/C contact of safety relay
Safety relay

FIG. 54.3
Conceptual diagram of safety system.

example, in Figure 54.3, safety relays remain in operation for the interface between the networked control system and the robot. Newer systems, such as those used by BMW at their Dingolfing plant, make use of robots with integrated safety network gateways [16]. This enhances further the capabilities of the safety system through increased flexibility, elimination of safety I/O blocks, and the ability to obtain better diagnostic information from the networked devices. This suggests that the trend in safety systems is heading toward the integration of safety functions into the devices used for car manufacturing.

Communications

The need for industrial communication followed as a natural progression from the replacement of hard-wired control systems by programmable control. Whilst the first PLCs provided flexibility from a programming perspective and gave some reduction in wiring, large and complex wiring looms remained in use. Each sensor or actuator within a plant or machine would need to be wired back to the PLC chassis, as shown in Figure 54.4.

The introduction of communication networks allowed the distribution of the wiring throughout the manufacturing cells. Now, rather than running individual signal wires back to the processor chassis, the signals are connected to communication modules on the network, with a communication cable running back to the controller chassis. As well as reducing wiring complexity, the approach has provided additional benefits. For example, fewer cards are now required in the controller chassis. In addition, the intelligence of the communication protocol allows for sensors to be connected to the network directly, as shown in Figure 54.5.

The advantage of coupling sensors directly to the network is the enhancement of diagnostic capabilities. Where previously, a faulty sensor would be indicated by null signal, an intelligent sensor can differentiate between different types of problem and provide appropriate indication to the controller and operator. Taking the example of an optic sensor, it means that the optic sensor can provide indication that its lens is in need of cleaning, allowing a maintenance team to undertake appropriate preventative maintenance. In contrast, the first that a maintenance technician would know about a fault with a traditional, hard-wired sensor would be the fact that signals are not received by the control program as expected.

Different types of communication mechanisms and protocols have been developed for use in the industrial world and automotive users typically make use of one or more of these networks. These networks have different characteristics, for example, the number of nodes, lengths, media type, and level

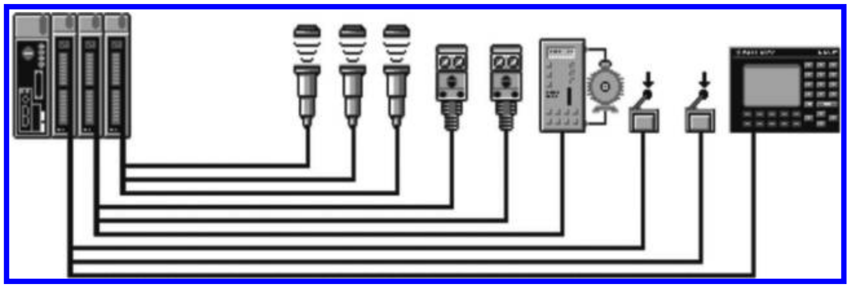

FIG. 54.4
Traditional wiring of sensors, actuators, and visualization.

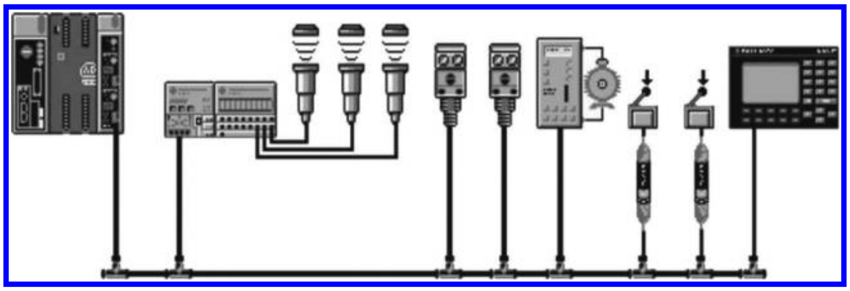

FIG. 54.5
Wiring of sensors, actuators, and visualization using an industrial communication network.

of determinism. To give an example, an industrial network that makes use of fiber-optic media may not be suitable for applications in which the communication media needs to pass along a robot arm as there is a risk of fiber breakage while the robot is in operation. In this context, flexible copper cable is most appropriate. Furthermore, application requirements may dictate the use of networks in a particular way. An example of this is a body assembly cell in which different end-effectors are fitted to a robot arm. Potentially, each tool may require its own I/O devices, and connectivity is required between the tool and the programmable controller. A mechanism by which connectivity through a tool changer can be achieved is explained by Piggin et al. [17]. The concept was extended to safety systems by Hajarnavis and Young [18].

An example of how the functions within a car plant might be allocated to each network is shown in Figure 54.6. This shows four different networks: an information layer for connectivity between the plant and enterprise systems, a control layer for interlocking between controllers, a device layer for interface between controller and I/O devices, and a safety network.

Examples of networks used by automotive plants include DeviceNet for connectivity to sensors and ControlNet for the connection of HMI systems and interlocking signals between the processors in a DCS. The advantages of this approach are as follows:

- *The provision of clear functional segmentation:* A fault on one of the networks will not affect the operation of another. Similarly, expansion and modification in one of the domains can be achieved without an impact on the others.
- *System clarity:* It is clear which part of the system corresponds to specific parts of the cell functionality.

The disadvantages of this approach are as follows:

- The need for knowledge of several different technologies for design, configuration, and maintenance
- A spare parts stock for each of the technologies

However, in response to the challenge of managing, maintaining, and adapting production systems using multiple networks, a number of manufacturers have started to simplify their automation systems by reducing the number of networks in operation. One mechanism by which this is being achieved is through the use of Ethernet to achieve the functionality previously implemented using multiple networks. The selection of Ethernet owes to its prevalence in the commercial space, which provides the economies of scale and cost savings provided by the use of standard off-the-shelf components. In practice, industrial Ethernet comes in a number of different

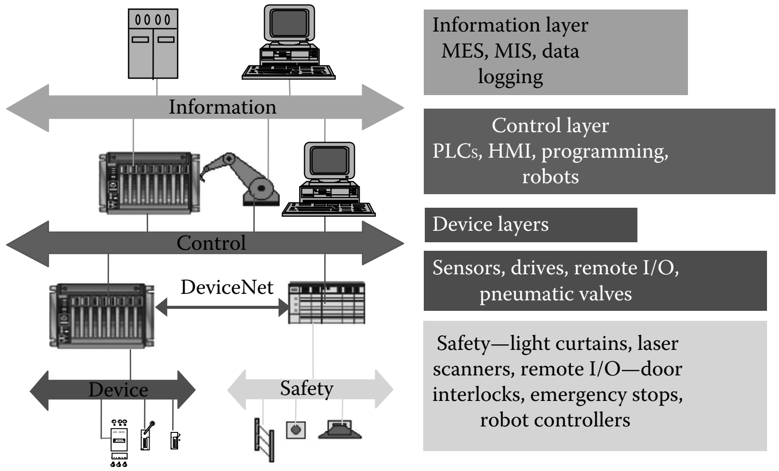

FIG. 54.6
Traditional multi-network plant architecture.

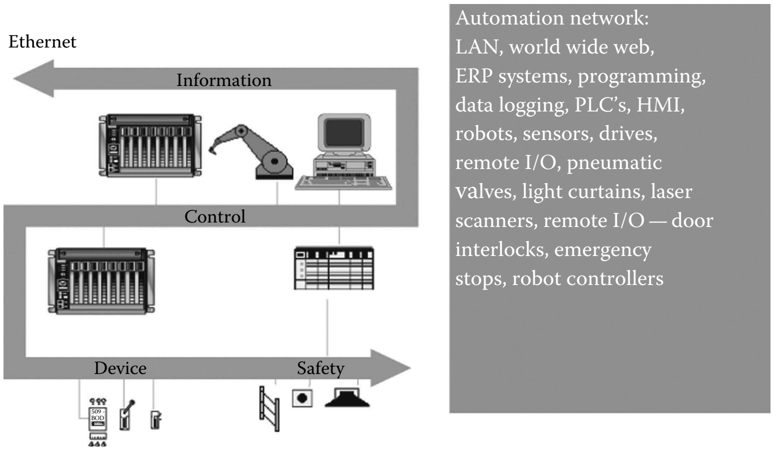

FIG. 54.7
Converged ethernet network.

forms, each with their own characteristics. For example, solutions such as EtherCAT and PowerLink are networks that provide extremely fast communication throughput but have little in common with other solutions such as Modbus/TCP or EtherNet/IP—both industrial Ethernet solutions that use the same network infrastructure as conventional Ethernet implemented in the commercial world.

The implementation of industrial Ethernet solutions within a factory typically follows one of two approaches—one in which several independent networks are implemented, or the use of one network for all communication functions. The former approach has the advantage of retaining system segmentation, whilst allowing the standardization on one technology. In contrast, the latter provides greater flexibility but requires a higher skill level to implement and manage.

Most contemporary implementations use physically segmented Ethernet networks although it is a stated desire of some manufacturers to reduce the number of networks over time. An image showing how a single network may look is shown in Figure 54.7. Once industrial functions have been merged into a single network, there is further potential to use the network for additional functions. The Converged Plantwide Ethernet Guide from Rockwell Automation [19] and Cisco provides guidance on how an Ethernet network can be configured to allow network convergence to encompass all industrial functions together with traditional office-based productivity functions. This convergence has the potential to allow diverse and disparate functions such as IP telephony and I/O control to share the same physical infrastructure.

CONCLUSIONS

Although parts of the global automotive industry are renowned for having a conservative attitude and for showing resistance to change, the combination of business pressures and technological improvements will mean that the next generation of production facility will have little in common with the original factories that gave birth to automation technology in the 1960s.

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